The Relationship Between Wave V of the ABR and Speech Recognition Threshold Outcomes in Children

Capstone Project

Presented in Partial Fulfillment of the Requirements for the Doctor of Audiology Degree in the graduate school of The Ohio State University

By

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Abstract

Given the increasing number of cochlear implant patients from ages 12 months through 2 years 11 months, the ability to determine post-operative speech outcomes is a highly sought after yet unpredictable measure to help determine cochlear implant candidacy in children. While there are several predictive measures of speech outcomes in adults' post-cochlear implantation, the need to better predict this variable in children can be a useful tool, if ever identified. The purpose of this study was to determine if the presence of a pre-operative auditory brainstem response (ABR) wave V present at 90 dB nHL in pre-lingually deafened children will be related to speech awareness or recognition thresholds (SAT/SRT) post-operatively once they receive at least one cochlear implant. While improvements in speech reception thresholds were noted from the subjects' one month follow up appointment to their last known appointment, these improvements were non-significant between the two group mean when they were compared to each other via a single-factor ANOVA test.

Dedication

I would like to dedicate this capstone project to my husband, Ben. Without this unrelenting support and understanding these last four years I might not have ever ventured to the great state of Ohio to fulfill my dreams of becoming an audiologist.

Acknowledgements

This capstone project could not have been completed without the support and guidance of my capstone advisor, Dr. Christina Roup. I am a better researcher, writer and observer of all things quantitative because of her honest and unwavering assistance. My sincere gratitude is also extended to the audiology department at Nationwide Children's Hospital in Columbus, Ohio, who provided me with data for this project. I would also like to acknowledge The Ohio State University Au.D. class of 2011. These wonderful women helped to make this four year long journey towards our careers fun despite the long hours of hard work both in and out of the clinic. Finally, I would like to extend my thanks to the faculty of the audiology department and clinic staff, in particular my capstone committee members, for their continued support of my education while at OSU.

Vita

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Fields of Study

Major Field: Audiology

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Auditory Behavior in Everyday Life (ABEL)

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American Speech-Language Hearing Association (ASHA)

Auditory Steady State Response (ASSR)

Auditory Brainstem Response (ABR)

Behavior Observation Auditory (BOA)

Central Auditory Processing (CAP)

Children’s Hospital of Philadelphia (CHOP)

Cochlear Implant (CI)

Communicative Development Inventory (CDI)

Communicative & Symbolic Behavior Scales (CSBS)

Conditioned Play Audiometry (CPA)

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Decibel Hearing Level (dB HL)

Distortion Product Otoacoustic Emissions (DPOAEs)

Early Speech Perception test (ESP)

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Goldman-Fristoe Test of Articulation (GFTA-2)

Identifying Early Phonological Needs (IEPN)

Infant-Toddler-Meaningful Auditory Integration Scale (IT-MAIS)

Joint Commission on Infant Hearing (JCIH)

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Universal Newborn Hearing Screening (UNHS)

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Word Intelligibility by Picture Identification (WIPI)

Word Recognition Score (WRS)

CHAPTER 1

Introduction

The introduction of the cochlear implant in the 1970s allowed for the first time adults that were pre-lingually deafened the opportunity to utilize their organ of hearing in a way that was previously untapped. By surgically implanting an electrode deep within the inner ear structure, or cochlea, and securing the majority of the device within the skull, auditory neurons that transferred sound information from the ear to the cortex were again receiving information. This rejuvenation of the auditory pathway led to the belief that children that were pre-lingually deafened could take advantage of their inherent neural plasticity, and subsequently learn to make use of the electrical simulation received via a cochlear implant in much the same way a child born with normal hearing would. Numerous studies have since concluded that children with cochlear implants who are brought up using spoken language have similar language outcomes to age matched peers (Dorman, Sharma, Gilley, Martin & Rolan, 2007; Robbins, Koch, Osberger, Zimmerman-Phillips & Kishon-Rabin, 2004; Geers, Nicholas & Sedey, 2003). The cochlear implant is a valuable medical device for treating profound hearing loss. The insertion of the stimulating electrode, however, will inevitably partially, if not fully, damage the fragile internal structure of the cochlea. This damage results in the loss of any residual hearing the implanted ear might have had, making it imperative that proper audiological evaluation of children with hearing impairment be completed in order to determine if a cochlear implant is truly needed or if hearing aids are instead a viable option to help the child learn speech and language.

Cochlear implants are now being utilized in an increasing number of pediatric cases as a treatment for severe to profound hearing loss (Robbins, Koch, Osberger, Zimmerman-Philips & Kishom-Rabin, 2004; Geers, Brenner & Davidson, 2003; Sharma, Dorman & Spahr, 2002). Given the increasing numbers of cochlear implants among prelingual children, pre-operative assessments of the potential for speech understanding, such as presence of an Auditory Brainstem Response (ABR) wave V, is becoming increasingly important. One main reason for this is the continual lowering of the age limit for cochlear implantation by the Food and Drug Administration (FDA) (Johr, Ho, Wagner, & Linder, 2008; Valencia, Rimell, Friedman, Oblander & Helmbrecht, 2008). Studies done by Johr et al. and Valencia et al. have determined ear surgery in children less than one year of age to be safe, which is vital for the facilitation of earlier cochlear implantation. Current research suggest that the earlier spoken language is introduced to a pre-lingually deafened child, the better their overall speech and language outcomes are in comparison to normal hearing aged matched peers as long as cochlear implantation occurs during a set “critical period” of less than 7 years of age (Dorman, Sharma, Gilley, Martin & Rolan, 2007; Robbins, Koch, Osberger, Zimmerman-Phillips & Kishon-Rabin, 2004; Geers, Nicholas & Sedey, 2003). Research completed by Sharma and her colleagues also suggests that the shorter the duration of deafness, approximately 3.5 years or less, will increase the likelihood of age-appropriate cortical responses, which are a necessary precursor to developing age-appropriate speech and language (Sharma, Dorman & Spahr, 2002). This sensitive period in which spoken language has the highest probability of developing is related to the maximum neural plasticity of the auditory pathway (Sharma, Dorman & Spahr, 2002). Neural plasticity, in reference to the implantation of pre-lingually deafened children, refers to the development of and ability of the auditory cortical areas to adapt and change to receiving auditory input (Dorman, Sharma, Gilley, Martin & Roland, 2007). Stimulation via a cochlear implant in a child that is pre-lingually deafened provides the necessary auditory information to develop these pathways, and there is evidence to show that earlier implantation takes advantage of this neural plasticity (Robbins et al., 2004; Sharma et al., 2002).

There are many predictive measures of speech recognition outcome with a cochlear implant in adults with severe to profound hearing loss, such as post-lingual onset of hearing loss and residual hearing ability. Most pediatric patients, however, cannot provide reliable behavioral measurements of hearing sensitivity or acuity. They therefore present a challenge in assessing potential benefit from a cochlear implant (Dorman et al., 2007; Dowell et al., 2004). It has been well established that cochlear implantation under three years of age is optional for maximal auditory cortical development and growth (Dorman, Sharma, Gilley, Martin & Roland, 2007; Taitelbaum-Swead, Kishon-Rabin, Kaplan-Neemnan, Kronenberg & Hildesheimer, 2005; Geers, Brenner & Davidson, 2003; Geers, Nicholas & Sedey, 2003; Sharma, Dorman & Spahr, 2002). Promising research has been conducted by Sharma, Dorman & colleagues using

Cortical Auditory Evoked Potential responses (CAEPs) and Positron Emission Tomography (PET) scans in children (Dorman Sharma, Gilley, Martin & Roland, 2007; Sharma, Gilley, Dorman & Baldwin, 2007). Research has clearly identified that early electrical auditory stimulation through cochlear implants produces stimulation to auditory pathways that were previously not receiving an auditory signal (Dorman et al., 2007). The results from Dorman et al. (2007) were recorded via the long latency auditory cortical evoked potentials P1 and N1 in conjunction with PET scans and demonstrate that if a child receives a cochlear implant before 18 months of age, the more likely auditory pathways will develop similar to age matched peers. Most facilities across the country, however, are unable to easily access the CAEP equipment and CAEP testing is expensive. Current methods of measuring hearing sensitivity in young children, such as the ABR, may be correlated with pre- and post-cochlear implant Speech Recognition Thresholds (SRT) measures. For instance, the ABR, which is used to determine the integrity of the auditory nerve, may be correlated with post-implant outcomes of speech recognition, specifically the SRT.

The ABR, which is used to determine the function of the auditory nerve in the pediatric population, may be correlated with post-cochlear implant outcomes of speech recognition, specifically the SRT. The presence of an ABR wave V at 90 dB nHL in a pediatric patient provides confirmation of neural integrity (Star, Amlie, Martin & Sanders, 1977; Hecox & Glambos, 1974). It follows that stimulation of an intact auditory nerve via cochlear implantation would lead to the successful development of speech and language outcomes for prelingually deafened children. Conversely, the lack of an

ABR wave V at 90 dB HL may suggest a lack of neural integrity and the potential for poor speech and language development post-cochlear implantation. The ability to predict the potential for positive speech and language outcomes prior to cochlear implantation in young children would be beneficial for both treatment planning and counseling of parents (Nikolopoulos, Ginnin & Dyar, 2004). The purpose of the study, therefore, was to determine if the presence or absence of a pre-cochlear implant ABR wave V in prelingually deafened children identified by 2 years of age was indicative of predicting SRT outcomes post-cochlear implant.

CHAPTER 2

Literature Review

I. Pediatric Hearing Assessment

To properly assess an infant with a suspected hearing loss for cochlear implantation it is vital to follow the established guidelines for audiologically testing pediatric patients set forth by the compiled evidence based practice guidelines published by the governing bodies for the profession of audiology. With the advent of universal newborn hearing screening (UNHS) and its utilization across the majority of the country, professionals from several key disciplines met in 2000 and 2007 to form the Joint Committee on Infant Hearing. The latest document, produced from the last meeting in 2007, states that screening the infant for hearing loss prior to leaving the hospital is a vital first step in early identification (JCIH, 2007). This can be done with either an ABR or via Otoacoustic Emissions (OAE). Once an infant has failed their UNHS, or there is parental or medical concern, The American Academy of Audiology (AAA) as well as the American Speech-Language and Hearing Association (ASHA) have established guidelines for testing of infants and children once a need for assessment is established (AAA, 2000; ASHA, 2004a; ASHA 2004b). Among these protocols, an ABR is recommended to estimate hearing thresholds for pure tones until the age when behavioral results can confirm the ABR results (AAA, 2000; ASHA, 2004a; ASHA 2004b).

As an ABR is needed to verify early identification of hearing loss and serves as one of the main factors in cochlear implantation criterion for young children, all subsequent audiological best practice protocols will be in reference to assessing children from birth to 5 years of age. It is pertinent with any age patient to establish a through case history, as well as an otoscopic evaluation prior to performing any testing. Ceruman management, audiologic rehabilitation status, and behavioral observation might also be utilized prior to assessment of the child, depending on the needs established during the case history and otoscopic examination (AAA, 2000). It is also necessary to obtain ear specific information, and it should be noted that multiple appointments might be needed to gather all necessary audiologic data (ASHA, 2004b; AAA, 2000).

Physiologic testing is a key component to testing children with a suspected hearing loss, in particular for infants less than 6 months of age (AAA, 2000). It is recommended by both AAA and ASHA that acoustic immittance measures be done to assess the middle ear status prior to further diagnostic testing. This would include tympanometry and acoustic reflexes (ASHA, 2004b). However, when testing infants under 4-6 months of age standard protocols for these measures might be confounded due to a young infants ear anatomy. And, a 1000 Hz probe tone or multifrequency tympanometry is recommended instead of the standard 226 Hz probe tone (Hunter, Tubaugh, Jackson & Propes, 2008; ASHA, 2004b). Another important diagnostic measure to undertake is OAE testing, either as Distortion Product Otoacoustic Emissions (DPAOEs) or as Transient Evoked Otoacoustic Emissions (TEOAEs) in order to assess the function of the outer hair cells of the cochlea (AAA, 2000; ASHA, 2004b). Prior to 6 months of age it is also imperative to obtain a diagnostic ABR, as opposed to the screening method obtained for the UNHS mentioned in the above. It has been established that the ABR for children under 18 months is different from an adult response, and different norms should be utilized in order to determine if a hearing loss is present (Stockard, Stockard & Coen, 1983; Hecox & Galambos, 1974). Pure tone air conduction as well as bone conduction thresholds should be obtained for each ear, in order to assess each ear's hearing status (Hecox & Galambos, 2008; AAA, 2000; ASHA 2004b) does not recommend the use of a click-evoked ABR, as the results yield a wide frequency response and therefore does not focus on specific speech frequencies as pure tone air and bone conduction does. The auditory steady-state response (ASSR) is noted by ASHA to be a promising test for diagnosing hearing loss in children, though more clinical research needs to be completed and replicated in order to ensure the tests application in diagnosing pediatric hearing loss. New research in the field of CAEPs has preliminarily yielded good results, with validity and reliability measures in a research setting indicating that these tests might fit into the audiological test battery. CAEPs measure in particular the P1 response, which is a physiologic response generated by the auditory thalamic and cortical sources (Doorman, Sharma, Gilley, Martin & Roland, 2007). Delays in this response peak and amplitude degradation indicate the amount of hearing loss, as well as promising research indicating the status of the cortical auditory pathway maturational status (Doorman, Sharma, Gilley, Martin & Roland, 2007; Sharma, Dorman & Spahr, 2002).

While physiologic measures of hearing acuity are crucial for fitting infants and patients that lack the ability to provide reliable behavioral thresholds, it is still pertinent to obtain behavioral thresholds as soon as the child is able to perform the task that is appropriate given their age and cognitive status (ASHA, 2004a; AAA, 2003). What remains critical, however, is the utilization of not only age appropriate tasks but also language appropriate tasks. This will allow the child's progress with amplification via hearing aids or cochlear implants over time to be monitored (ASHA, 2004b). There are currently three main behavioral methods to obtain audiological thresholds in children under the age of 5: Behavioral Observation Audiometry (BOA), Visual Reinforcement Audiometry (VRA) and Conditioned Play Audiometry (CPA). While each method can be used to obtain reliable and repeatable thresholds, it should be noted that as with any behavioral threshold test, the potential for external factors to influence the test results is always a concern (Madell, 2008a). Since very young infants are subject to inattentiveness, varying states of alertness, or are unresponsive to visual stimuli, in addition to the need for subjective interrupting of responses by a test assistant, BOA can prove to be ineffective in obtaining behavioral thresholds. It should also be noted that the Pediatric Amplification Protocol set forth by AAA does not endorse BOA as a valid means of providing audiological thresholds for infants (AAA, 2003). Visual Reinforcement Audiology on the other hand can be preformed on infants approximately 5 months of age or older, and responses will often be easier to detect when the infant is responding due to the conditioned response nature of the test (ASHA, 2004b; Primus & Thompson, 1985; Moore, Wilson & Thompson, 1977). To complete this test, the child is placed on the lap of the parent or in a high chair, and head turns are elicited in response to stimuli. These head turns are rewarded with a visual stimulus, such as flashing lights, a moving toy, etc., located on the side of the head where the sound was heard (Madell, 2008c). While the preferred responses would come using insert ear phones and pure tone stimuli for each ear individually and all frequencies, in younger children this is not always attainable. Multiple appointments should be utilized if necessary, as well as different types of stimuli, such as narrow band noise or warble tones Madell, 2008c; ASHA 2004b; AAA, 2003). If the child will not tolerate insert headphones, sound field testing may be utilized, though responses will likely be supra threshold, and ear specific information should be obtained at follow up appointments (ASHA, 2004a; AAA, 2003). Conditioned Play Audiometry, or CPA, can be attempted once the child has a cognitive age of between 2 to 3 years old, with children closer to 3 being more likely to complete the task and children closer to 2 less likely to complete the task (Madell, 2008b; Thompson, Thompson & Vethivelu, 1989). When play audiometry is used to obtain audiologic thresholds, it is critical that the child learns that they need to hear the stimulus before performing the conditioned task (Madell, 2008b). As with VRA, it is necessary to obtain ear and frequency specific information while performing CPA, and changing ears, stimulus, or task may facilitate this (Madell, 2008; AAA, 2003). Speech Awareness Thresholds (SAT), Speech Recognition Thresholds (SRT) or Word Recognition Scores (WRS) should only be attempted if the child has the necessary language to complete these tasks, and can include point-to-the-picture tasks such as the Northwestern University- Children's Perception of Speech (NU-CHIPS) word recognition test or the Word Intelligibility by Picture Identification (WIPI) word recognition test (ASHA, 2004a; Zwolan et al., 1997). Tests most commonly used with cochlear implant teams include the Early Speech Perception test (ESP), the Potato Head Task, and the Lexical Neighborhood Test (LNT) or Modified Lexical Neighborhood Test (MLNT) (Madell, 2008d; ASHA, 2004a; AAA, 1995; Robbins, 1994; Moog & Geers, 1990). It should again be cautioned that the previously mentioned word recognition and speech detection tests should only be utilized if the child has appropriate language skills. Speech Awareness Thresholds (SAT) or detection of the Ling 6 Sounds may be more useful that a WRS or SDT test if the child is old enough (Madell, 2008d; Ling, 1976), as these tests focus on speech detection and can be used to help track the child's hearing sensitivity over time in addition to other aided detection tests (Madell, 2008d; ASHA, 2004a).

Questionnaires can also be useful for the parents and/or primary caregivers of very young children that are suspected of having a profound hearing loss, as they help label and objectify the behaviors, or lack of behaviors, that the parents and/or primary care givers are seeing Specifically for infants and toddlers the Infant-Toddler-Meaningful Auditory Integration Scale, or IT-MAIS, is a useful tool utilized by the audiologist to gather more information from the child's caregivers, as it focuses on describing typically developing auditory behavior and the frequency of occurrence of each behavior (Zimmermann-Philips, Robbins & Osberger, 2001). The IT-MAIS is very similar to the Auditory Behavior in Everyday Life (ABEL) and Little Ears questionnaires (Yin, 2008). The PRISE, or Production Infant Scale Evaluation, is another questionnaire that focuses on vocal development and vocal quality (Osberger, Robbins & Trautwein, 2006). While the use of questionnaires for assessment are not directly cited as a necessary part of the pediatric hearing evaluation by AAA or ASHA due to their non-standardized nature, they can prove to be useful counseling tools for caregivers that help them clarify their expectations and more clearly articulate their observations (Scherf et al., 2009; Osberger, Robbins & Trautwein, 2006; Taitelbaum-Swead et al., 2005; AAA, 2003).

II. Current Standards in Audiology Regarding Cochlear Implantation

Cochlear implant candidacy is determined by the success/outcomes of the physiological and behavioral tests appropriate for the child's developmental and cognitive age. In addition to the test measures discussed in the previous section, an appropriate hearing aid evaluation is also recommended by AAA and ASHA, as well as JCIH (JCIH, 2007; ASHA, 2004; AAA, 2003; AAA, 1995). However, while the FDA still regulates the internal and external devices, it is up to the manufacturers and individual implantation teams to determine what criterion they will use based on professional standards, emerging literature, and past success.

Although the FDA does not currently have precise cochlear implantation guidelines, they do stipulate that they are for use in severe to profoundly deaf children and adults (FDA, 2010). In the United States, the two main cochlear implant manufacturers are Cochlear Americas and Advanced Bionics. Cochlear Americas first received FDA approval under its previous name, Cochlear Corp., in 1984 for the 3M CI, which preceded Advanced Bionics FDA approval by 13 years. This gap in approval allowed for Cochlear America's majority share of the market, making the introduction of the third company to receive FDA approval in 2001, Med El, virtually insignificant (FDA, 2011).What the FDA does stress for cochlear implantation criterion is that each manufacturer develop, research and institute its own set of guidelines that are tied to the development, research and approval of individual medical devices; in this case, cochlear implants (FDA, 2011; 2010). Also, the minimum requirements listed to be a cochlear implant candidate include children ages 12 through 24 months old be diagnosed with a profound hearing loss with a pure tone average of 90 dB HL or poorer, and for children over 24 months of age a severe or profound sensorineural hearing loss with a pure tone average of 70 dB HL or poorer must be diagnosed (FDA, 2011; 2010; Alexiades et al., 2008).

Cochlear Americas, the largest cochlear implant manufacture in the United States, has two different implantation guidelines for pediatric candidates. The first set of guidelines is aimed at children ages 25 months to 17 years, 11 months. To be a cochlear implant candidate in this age range, the child must have a severe to profound sensorineural hearing loss bilaterally, lack of progression in auditory skill development, no other contradictory medical conditions, realistic expectations of the primary care givers and high motivation for success, and MLNT scores of 30% or less in the best-aided condition (children 25 months to 4 years 11 months) or LNT scores of 30 % or less in the best-aided condition (children 5 years to 17 years, 11 months) (Cochlear Americas, 2010). For children younger than 25 months, however, there is a different criterion that factors in the difficulty of obtaining behavioral results from children of such a young age (Valencia et al., 2008). To be considered for cochlear implantation, a child from the ages of 12 months to 24 months needs to be diagnosed with a profound sensorineural hearing loss bilaterally, obtain limited benefit from appropriately fit hearing aids, show a lack of auditory skill development, have no other medical contradictions, and the primary caregivers must demonstrate high motivation coupled with realistic expectations (Cochlear Americas, 2011; 2010). Another source of cochlear implantation guidelines comes, surprisingly, from the U.S. Medicare/Medicaid Coverage Issues document. While Medicare/Medicaid has no medical basis for determining cochlear implant candidacy, these two government run health care coverage services often help determine candidacy guidelines in respect to individual CI teams across the country, as reimbursement is an ever-present factor in providing services in any health related field. Currently Medicaid states that in order for a child to be deemed eligible for cochlear implant surgery, children ages 2 through 17 years of age that are pre-lingually or post-lingually deafened will qualify, and that the diagnosis of bilateral profound sensorineural deafness must be demonstrated by the lack of progress on age appropriate closed-set word identification tasks with the use of appropriate amplification (Centers for Medicare & Medicaid Services, 2010). These guidelines are in addition to the general guidelines that apply to both children and adults. This includes no contraindications to surgery, and an FDA approved device (Centers for Medicare & Medicaid Services, 2010). In addition to the above requirements, which are consistent with the current FDA and Cochlear Americas standards for cochlear implantation, Medicaid also includes the following criterion: that a candidate must have an absence of middle ear infection, accessible cochlea, and no lesions or absence of auditory nerve or acoustic areas of the central nervous system; cognitive ability to gain benefit from auditory cues; and a desire to obtain rehabilitation (Centers for Medicare & Medicaid Services, 2010). Notably, the criterion of cognitive ability and the ability to gain benefit from auditory cues has come under debate in recent years, with the general conclusion that quality of life improvements vary from family to family in children with cognitive and other developmental delays, and that determining cognitive ability can help in counseling parents on realistic expectations (Edwards, Frost & Witham, 2006). It should also be noted that Medicaid states that this coverage is only applicable to the surgery and not for any pre or post testing, rehabilitation, etc. that might incur as a result of the cochlear implant surgery.

Even though the FDA, Medicaid and the cochlear implant manufacturing companies have an incredible influence on how individual programs set up their implant cochlear candidate criterion, it is up to each individual CI program to determine and enforce their criterion. These criterions are based on a protocol the cochlear implant team for each hospital sets up based on evidence based practice, as well as their own experiences working with children with profound bilateral hearing loss and their families. There are numerous programs at hospitals across the country that perform cochlear implant surgery, but only three programs in particular will be highlighted due to the longevity of their implant programs and based on their clinical excellence and reputation. The House Ear Institute of Los Angeles, California, has long been recognized as a leader in hearing and balance disorders since its founding in 1964 (House Ear Institute, 2011a). Dr. Howard P. House, founding member and M.D. not only founded the House Ear Institute, but also helped design and implant the first generation of cochlear implants.   The House Ear Institute, like at all locations where cochlear implant surgery is preformed, utilizes a “team” approach, and list several criterion that they use as implantation guidelines for children. These guidelines include: a through audiological evaluation that yields a bilateral severe-profound hearing loss, be 12 months of age or older, receive inadequate benefit from hearing aids that results in a delay in auditory and aural growth, and have evaluations conducted by the in house speech language pathologist, psychologist and surgeon (House Ear Institute, 2011b).

Two other nationally recognized programs include the Boystown National Research Hospital in Omaha, Nebraska and the Children’s Hospital of Philadelphia in Philadelphia, Pennsylvania. Much like the House Ear Institute of Los Angeles, these two institutions emphasize many of the same candidacy criterions; however, they also demonstrate difference. At Boystown National Research Hospital cochlear implant candidacy criterion includes that the child be 12 months of age or older, have a bilateral profound hearing loss for children under 18 months of age, have a bilateral severe-profound hearing loss for children over 18 months of age, have limited benefit from the use of hearing aids, have limited auditory development and growth, be medically cleared to undergo surgery, and have no physical conditions that would interfere with the placement of the cochlear implant. Furthermore, the cochlear implant team at Boystown also includes realistic expectations from receiving a cochlear implant and a commitment to continue follow up appointments as a candidacy requirement (Boystown, 2010). Children’s Hospital of Philadelphia (CHOP) lists similar criterion for cochlear implantation, listing that the child must be between 12 months through 17 years of age (though evaluation for surgery can begin prior to the age requirements), a severe-profound bilateral hearing loss, limited benefit from hearing aids, and a strong family commitment. CHOP also denotes that the child must have or be willing to participate in an educational plan that emphasizes the development of auditory skills (CHOP, 2011). While these three institutions follow the guidelines set forth by the FDA as well as the cochlear implant manufacturers, it is clear that variation exists even among highly regarded programs within the United States. Table 1 shows the overlapping and different cochlear implant criterion for the House Ear Institute, Boystown National Research Hospital and Children's Hospital of Philadelphia.

Table 1: Cochlear Implant Candidacy Criterion

CRITERION	***INSTITUTIONS***		
	House Ear Institute	**Boystown National Research Hospital**	**Children's Hospital of Philadelphia**
12 months or older w/profound bilateral hearing loss		X	
12 months or older w/severe-profound bilateral hearing loss	X		X
18 months or older w/severe-profound bilateral hearing loss		X	
Limited benefit from hearing aids	X	X	X
Limited auditory development	X	X	X
In-house evaluations by other professionals	X		
Medical Clearance		X	
No physical abnormalities to interfere with CI placement		X	
Commitment to follow up appointments		X	
Realistic Expectations		X	X
Education that emphasizes auditory development			X

III. Current Predictive Measures of Speech and Language Success in Children with Cochlear Implants

Currently, duration of deafness is the best indicator as to how a child with profound hearing loss will do with continued auditory skill and development later in life (Robbins et al., 2004; Sharma, Geers, Nicholas & Sedey, 2003; Dorman & Spahr, 2002). There is also an established positive correlation associated between duration of deafness and spiral ganglion cells. Specifically, the longer the duration of deafness, the more the spiral ganglion cells deteriorate, which are a necessary component of the auditory pathway (Dowell et al, 2002; Cooper, 2006). The younger the child receives their cochlear implant, the better their overall access to speech sounds and an increased chance for their auditory pathways to mature more like normal hearing children's. Several studies including those completed by Sharma et al and Robbins et al. indicate the neural plasticity advantages in the auditory pathways that indicate the need for a younger age of implantation, but ultimately in the clinical setting there are still some children implanted within the "critical period" that are not performing as well as their age-matched hearing impaired peers, let alone their hearing age-matched peers. Predicting which children will excel with their cochlear implants and which children might need more intensive, specialized language and speech development therapy is something yet to be achieved, as the majority of the cochlear implant's history the focus has been to implant those that were more likely to excel with the device (Cooper, 2006). A study conducted by Robbins et al. (2004) examined the correlation between age of implantation and auditory skill development. Results revealed that the children ages

12-23 months did gain auditory skills more similar to their hearing peers than the children ages 24-36 months (Robbins et al., 2004). In 2002 Dowell et al reported that positive speech performance outcomes were observed for adults with significant residual hearing who obtained cochlear implants (Dowell et al., 2002). Overall, 75% of these adult subjects obtained better speech understanding scores that their best aided test results. However these studies cannot be replicated in children yet, as there is not a large enough subset of early implanted children that can be included in these same measures (Dowell et al., 2004).

Questionnaires have also been utilized in an attempt to best predict who will be more successful with a cochlear implant. While the majority of these questionnaires focus on the post-lingually deafened adult cochlear implant population, Gantz et al. (1993) utilized a battery of measures, including audiological, historical, electrophysiological and psychological variables, to predict which subjects would succeed with their devices. Gantz and colleagues found at nine months post activation their subjects obtained a positive correlation of 0.81 on the Iowa sentences test and a positive 0.78 correlation on the NU-6 WRS test. But again, this study was conducted on adult listeners and no data is available on pediatric cochlear implant users (Gantz et al., 1993). One of the few questionnaires meant to evaluate children pre and post implantation is the Auditory Behavior in Everyday Life (ABEL). This is completed by the parent, and assesses the child's listening behavior in many environments (Osberger, McConkey & Trautwein, 2006). The ABEL includes detection, discrimination, recognition of environmental sounds, and speech sounds (Ying, 2008). The IT-MAIS is similar to the

ABEL though it does not go as in depth in the variety of questions or situations listening behavior is observed in. The audiologist, not the parent, is the one who fills out this questionnaire and can provide a different perspective when estimating pediatric outcomes for cochlear implant pre-operatively. For the IT-MAIS, a lower score indicates a child's need for audiological intervention to develop auditory skills including vocalization, alerting to sounds in the environment and obtaining meaning from sounds (Robbins et al., 2004). A higher score indicates that the child has appropriate amplification in place and is successful in auditory skill development, alerting to environmental sounds and obtaining meaning from sounds (Robbins et al., 2004). Robbins et al. (2004) showed that there was a positive correlation of 0.82 for the children implanted ages 12-18 months, indicating a rapid improvement in their IT-MAIS scores at 3, 6 & 12 months post cochlear implantation activation (Robbins et al., 2004). Med-EL, one of the three main manufactures of cochlear implants, has also developed a speech perception questionnaire called Little Ears. This evaluation is completed by the parents, and also assesses areas of audition covered in the IT-MAIS and the ABEL (Yin, 2008).

Other variables often used to help assess the potential for success with a cochlear implant include parent involvement and developmental delay of the child. Pediatric cochlear implant recipients whose parents are very involved in goal setting, attaining necessary habilitative services and choosing an educational model that emphasizes speech and spoken language tend to have better results with their devices post implantation (Alexiades et al, 2008; Cooper et al., 2006; Li, Bain & Steinberg, 2004;

Geers, Brenner & Davidson, 2003). As stated in the above, cochlear implants have, in the past, typically have been given to patients with the best chance of success. Developmental delay can play a factor in determining pre and post operative success due to the fact that children that fall into this category can be more difficult to obtain reliable results from (Alexiades et al., 2008; Shoup & Roeser, 2008; Cooper, 2006; Edwards, Frost & Witham, 2006).

New predictive measures using cortical auditory evoked potentials (CAEPs) have recently been introduced by Sharma and colleagues. These measures, when compared to age-matched peers, suggest that by measuring the development of the P1 latency, there is a critical period for implantation to achieve optimal cortical auditory pathway development (Dorman, Sharma, Gilley, Martin & Roland, 2007; Sharma, Gilley, Dorman & Baldwin, 2007; Sharma Dorman & Spahr, 2002). This has long been substantiated with previous studies, but with the use of new technology such as the functional Magnetic Resonance Imaging (fMRI) and positron emission tomography (PET), this development can be tracked on the cortical level. While these studies are in need of duplication and re-validation, results are promising and again validate the need to give children cochlear implants early if their parents desire them to use spoken language as their main mode of communication. For now, these methods are not used clinically.

IV. Post Implantation Measures of Speech and Language Success in Children with Cochlear Implants

When tracking success with cochlear implants post-operatively many of the afore mentioned methods of audiological testing are still utilized to obtain valid aided measurements of the child's hearing ability using their device(s) such as behavioral testing, including speech testing. Other post implantation measures rely heavily on the collaboration and team-work associated with early intervention teams, as speech language pathologists are vital to assessing the progress of a child's language development (Yin, 2008). Speech testing often included in this test battery include the production infant scale evaluation (PRISE), which focuses on vocal development; the Goldman-Fristoe Test of Articulation (GFTA-2), which can be used for children 2 years of age or older; the Identifying Early Phonological Needs test (IEPN); and the Speech Intelligibility rating (SIR). Language testing, which is also completed by a speech language pathologist, is also vital for the monitoring of auditory development in children with cochlear implants. Some of these tests include the Communication and Symbolic Behavior Scales (CSBS), the Communicative Development Inventory (CDI) which is filled out by the parent, the Reynell Developmental Language Scale (RDLS) for children aged 12 months through 6 years of age, and the preschool language scale (PLS), which can be administered from birth through 6 years 11 months (Ying, 2008; Cooper, 2006).

V. The Pre-Operative ABR and Post-Operative Speech Perception Scores in Children

While the afore mentioned testing methods of obtaining behavioral and electrophysiological hearing thresholds as well as parent surveys and questionnaires from children are all beneficial to assessing a child's hearing status, there remains the need to discover a true predictive measure of a congenitally deafened or pre-lingually deafened child. Obtaining this measure will provide more accurate counseling for parents considering cochlear implants for their children, and can also help determine necessary treatment options post-implantation (Madell, 2008d; Nikolopoulos, Gibbin & Dyar, 2004). Current research also strongly supports the need to complete behavioral speech testing in cochlear implant recipients of all ages, in particular for young children, as this provides an insight as to how the child is doing in every day situations. This population can have reliable hearing thresholds results obtained via electrophysiological testing, yet variation among cochlear implant recipients can be varied and unpredictable (Spencer, 2004; Dowell et. al, 2002; Tait, Lutman & Robinson, 2000). While there have been a few studies that looked at predicting speech outcomes in children via complex multi-faceted assessments utilizing questionnaires and behavioral testing, the electrophysiological assessment of the ABR is still the gold standard for identifying hearing loss in infants and young children (Star, Amlie, Martin & Sanders, 1977; Hecox & Glambos, 1974). Given that the ABR is the current preferred measure of auditory thresholds in young children, establishing a predictive measure for speech outcomes in these pre-lingually deafened children can greatly improve the identification of which children might additional intervention (as discussed by Nikolopoulos et al., 2004), as well as provide parents with more information as to whether they will give their child a cochlear implant or not and determination of educational settings for the child.

While this author was unable to find any other research studies that directly looked at the correlation of the ABR with speech outcomes in pre-lingually deafened children, there were studies that had observed similar outcomes via similar measures. Lee et al. (2007) examined the sentence understanding outcomes of children who had cochlear implants that had a PET scan prior to implantation (Lee et al., 2007). Lee and colleagues established that there is a positive correlation with a hypometabolism of the temporal cortex and better speech understanding of the Koren version of the Central Institute of the Deaf Sentence test. However, the test measures included sentence use, and while this is an exciting study it cannot be as readily done as an SAT or SRT test on a child; meaning, you would have to wait until the child is older to administer the test, as complex language and speech are needed to complete the outcome task. Giraud and Lee in 2007 also completed a similar study, which again utilized the PET scan to observe cortex metabolism as a predictor of speech outcomes. As with the study by Lee et al., Giraud and Lee observed a positive correlation with activity in the dorsal brain regions that include the left prefrontal and parietal cortices and better speech outcomes. Children with high levels of ventro-temporal metabolism, however, did not fare as well, and subsequently had lower speech outcome scores even after duration of deafness was factored out (Giraud & Lee, 2007). While both of these studies may very well prove to be the foundation for a new generation of assessment for pre-lingually deafened children, PET scanning is extremely expensive and there are only a select few facilities across the country that offer this kind of technology at this point in time.

Perhaps the study that has the most similarity to utilizing the pre-operative ABR as a predictor of post-operative speech outcome was completed by Nikolopoulous, Mason, Gibbin, O'Donoghue and Gerard (2000). Directly prior to cochlear implant surgery Nikolopoulous et al. observed promontory electrically evoked auditory brain stem responses (prom-EABRs) and placed children into two groups: one group had a clear wave V, and the other had no observable wave V (Nikolopoulous et al., 2000). Using a variety of open set and closed set speech tasks, as well as the CAP and Speech Intelligibility Rating (SIR) to assess speech outcomes of both groups, no correlation was found for either group regarding speech outcomes and the presence of absence of a pre-operative prom-EABR (Nikolopoulous et al., 2000). This again reiterates the need to exhaustively research all possibilities for utilizing the ABR as a predictive speech outcome measure, as no other study found by this author has come to that conclusion, aside from the fact that current promising measures such as PET scanning are currently out of reach of the majority of audiologists.

CHAPTER 3

Methods

The primary question motivating the current proposal was to determine if a relationship exists between the presence of a pre-cochlear implant ABR wave V and post-cochlear implant speech awareness or recognition outcomes in a pediatric population. In order to answer this question, ABR and SRT data were obtained from two groups of pediatric cochlear implant patients from Nationwide Children's Hospital, Columbus, Ohio. The two groups were defined based on their pre-cochlear implant ABR wave V status: either present or absent. For both groups, their post-cochlear implant speech awareness or recognition threshold data were compared to their ABR wave V results in order to determine if a relationship exists between the two measures. Specifically, it was hypothesized that Group 1 (present ABR wave V) would exhibit a significant positive outcome by exhibiting low a low SRT score post-cochlear implantation. Similarly, it was hypothesized Group 2 (absent ABR wave V) would exhibit a significant positive correlation with poor post-cochlear implant SRT outcomes.

Subjects for the present study were selected from the cochlear implant data base at Nationwide Children's Hospital in Columbus, OH that met the following criteria: 1) Group 1 had a present pre-cochlear implant ABR wave V at or above 90 dB nHL ; 2) Group 2 had have an absent pre-cochlear implant ABR wave V at or above 90 dB nHL; 3) cochlear implant surgery occurred between the ages of 6 months and 2 years, 11 months between January 1, 2004 and December 31, 2008; 4) there was no more that one year gap between identification of hearing loss and cochlear implantation; 5) all children were implanted with the Cochlear Nucleus 24 device; and 6) at least one follow-up appointment was included that contained valid SAT or SRT results. All identifying information was removed form the data prior to research review and each patient was randomly assigned an arbitrary numerical value in order to ensure patient privacy and confidentiality. It should be noted that the final speech measurement was either in Speech Recognition Threshold (SRT) or Speech Awareness Threshold (SAT), as some subjects did not have the language level to obtain an SRT at the time of their last appointment.

Twenty one children of both genders met the selection criterion listed above from the cochlear implant data base at Nationwide Children's Hospital in Columbus, OH. Thirteen children did not have a pre-operative ABR wave V present at 90 dB nHL, and eight children did have a pre-operative ABR wave V at 90 dB nHL. However, one subject from group two did not have a score for an SAT one month post-operative, as the cochlear implant was at the limits of the Neural Telemetry Response (NRT) of the cochlear implant. In total, twelve subjects were included for Group 2, which made the total sample size 20 subjects. The mean age of the children from Group 1 was 7 months at the time of identification, the mean age of cochlear implantation was 16 months and the mean time from identification of the hearing loss to cochlear implantation was 9 months. For Group 2 the mean age of the children was 9 months at the time of identification, the mean age of cochlear implantation was 19 months and the mean time from identification of the hearing loss to cochlear implantation was 9 months. Surgery dates and date of last known appointment were unknown, other than falling within the study guidelines.

Table 2: Mean Patient Information (in months).

	Group 1	Range	Group 2	Range
Age of Identification	7	1 – 21	9	2 – 17
Age of Cochlear Implantation	16	10 – 33	19	6- 12
Time Between Identification and Implantation	10	5 – 12	9	6 - 12

ABR data was obtained at Nationwide Children's Hospital on a BioLogic-Navigator auditory evoked potential machine from 2005. All recording was done via 2 channel air-conduction alternating click signals via insert earphones while using vertex and mastoid (Cz/A1 and Cz/A2) electrode placement sites. The window for sampling was set to 10.24 seconds and a sampling rate of 23.1 samples per second, which allowed for 256 responses to be collected. Gain for each channel was set to 150,000 Hz, with a low filter pass set to 100 Hz and a high filter pass set to 3,000 Hz for both channels. The SAT and SRT responses were recorded via MLV through either sound field testing or via insert earphones, depending on what the subject could tolerate.

Data from the present study was analyzed in order to determine if significant differences exist in the SRT between the two groups. A single factor ANOVA Test was used to compare mean SRTs between the group with a present wave V and the group with an absent wave V. Secondary analysis completed included a single-factor ANOVA to examine the subjects' variance at their one month follow up appointment, as well as for the mean patient speech thresholds one month post-op compared to their most recent speech threshold for each group.

CHAPTER 4

Results

Figure 3.1 presents the SRT/SAT results for both Groups 1 and 2. As can be seen in Figure 3.1, very little difference was present in SRT/SAT's between the two groups. Group 1 (present pre-operative ABR wave V) had a mean SRT/SAT of 17.5 dB HL post-operatively, whereas Group 2 (absent pre-operative ABR wave V) had mean SRT/SAT of 20 dB HL. Figure 3.2 presents each individual speech threshold reported for each subject at their last known visit. As can be seen in Figure 3.2, there is substantial variability across subjects, although the majority of subjects exhibited SRT/SATs in the normal hearing range. Figure 3.3 presents the individual SRT/SAT data as a function of appointment time: at 1-month post operative and at the most recent appointment. It is interesting to note that all subjects SRT/SATs improved between appointments. For Group 1, 8 out of 8 subjects were able to obtain a SAT at their one month follow up appointment, and 4 out of 8 subjects were able to obtain a SRT at their last known appointment. For Group 2, 12 out of 12 subjects were able to obtain a SAT at their one month follow up appointment, and 6 out of 12 subjects were able to obtain a SRT at their last known appointment. All 20 subjects were able to obtain a SAT score at their one month follow up visit, with 10 of the total subjects able to obtain an SRT at the last known visit.

A single factor ANOVA was preformed in order to determine if a significant difference existed in SRTs between Group 1 (present pre-operative ABR wave V) and Group 2 (absent pre-operative ABR wave V). Results of the single factor ANOVA test revealed that the mean difference in SRT was not significantly different between the two groups ($f_{1, 18} = -0.66$; $p > .05$). Secondary analysis results also yielded no significant differences in means across the two groups. Results of the secondary analysis single factor ANOVA test revealed that when comparing the SAT of Group 1 to Group 2 at the one month follow up appointment, there was a significant correlation between the two groups, indicating that they are indeed similar to each other ($f_{1, 18} = 0.73$; $p > 0.5$). For Group 1, the patients first speech threshold score when compared to their final speech threshold score at their last known appointment also had no significant difference ($f_{1,7} = 3.54_E^{-04}$; $p > 0.5$). This was also true for Group 2 ($f_{1, 11} = 1.87_E^{-07}$; $p > 0.5$).

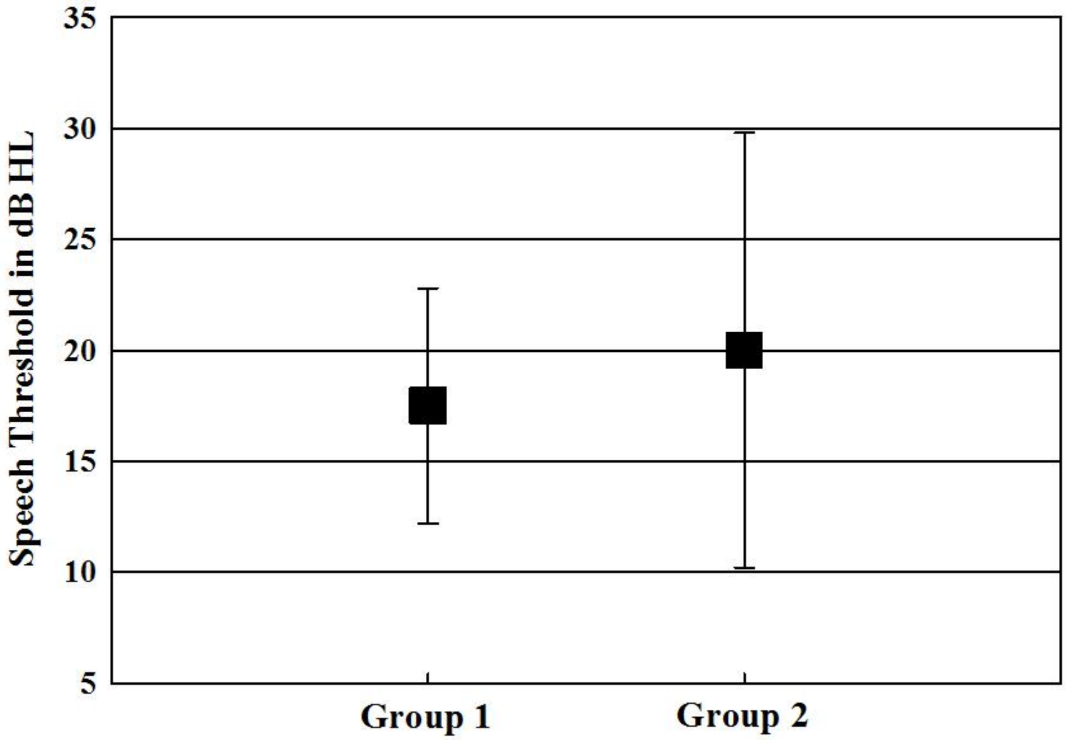

Figure 3.1. Mean speech threshold (dB HL) for Group 1 and Group 2 at last appointment.

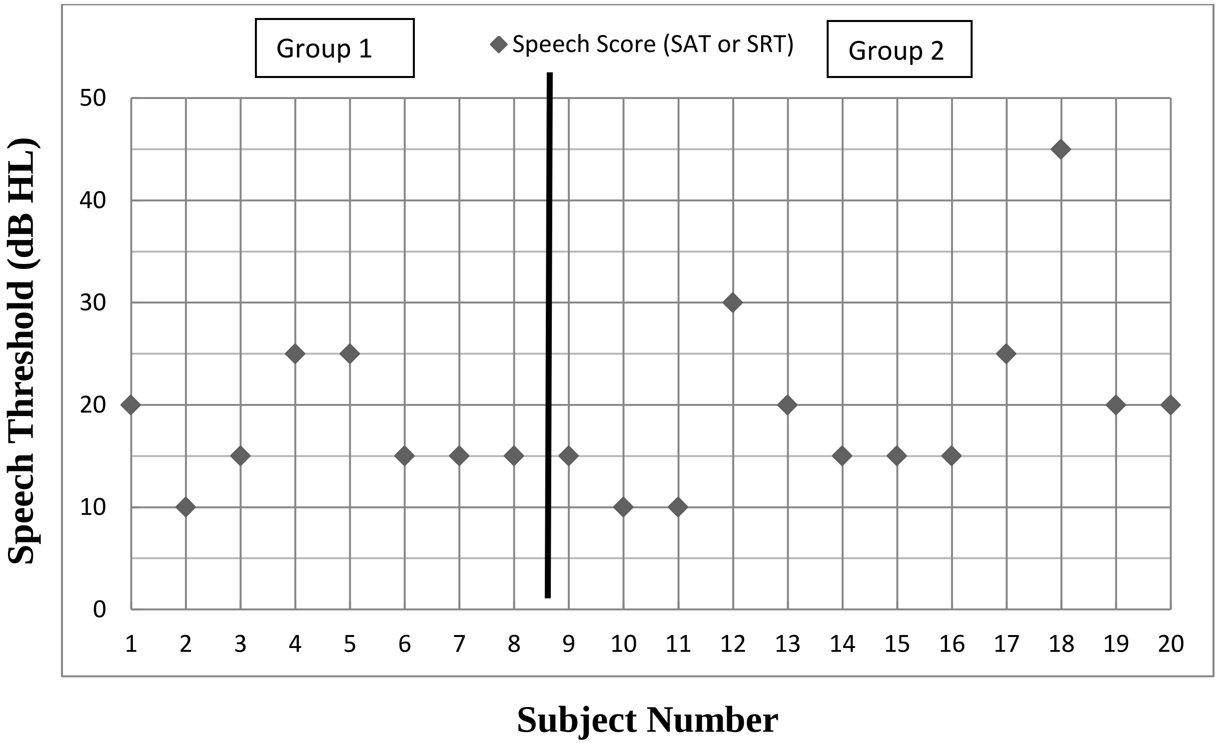

Figure 3.2. Post-Operative speech scores for individual subjects at last known appointment (Group 1 = Subjects 1 – 8, Group 2 = Subjects 9 – 20).

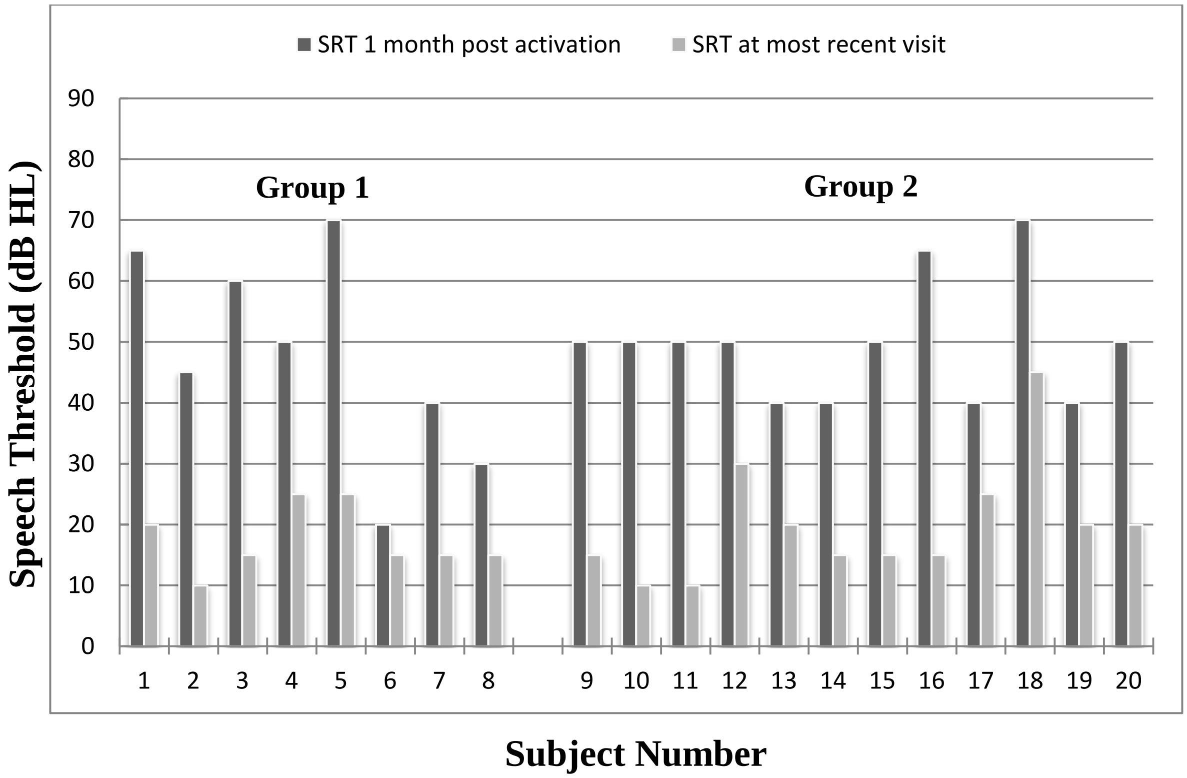

Figure 3.3. Post-Operative speech threshold for individual subjects at 1 month vs. the most recent appointment (Group 1 = subjects 1-8, and Group 2 = subjects 9-20).

CHAPTER 5

Discussion

The children in the present study, all of whom received a cochlear implant under three years of age, obtained similar speech awareness thresholds or speech reception thresholds. While improvements in speech recognition thresholds were noted from the subjects one month follow up appointment to their last known appointment, these improvements were not significantly different when you compared the two groups to each other (see Figure 3.1). Each Group also had a similar mean age of identification of hearing loss, mean age of cochlear implantation and mean time of identification of hearing loss to cochlear implantation. While these variables were not listed as items of importance in this study, these factors were deemed to have no significant influence on the outcomes of each group, as no significant difference was noted for any of these variables. However, it should be noted that individually, each subject had a significant improvement in their SAT or SRT score when comparing their 1 month appointment to their last known appointment. Overall, children from both groups obtained a speech threshold ranging from 10 dB to 45 dB (see Figures 3.2 and 3.3). At the last known appointment Group 1 obtained speech thresholds ranging from 10 dB HL to 25 dB HL, and Group 2 obtained speech thresholds ranging from 10 dB HL to 45 dB HL. While this factor was not specifically analyzed for this study it was interesting to note that Group 1, which was the experimental group that had a present pre-cochlear implant ABE wave V at or above 90 dB nHL, was the group with the smallest range of results. In contrast, Group 2 had a range of 35 dB HL (the group with an absent pre-cochlear implant surgery). The mean speech threshold for Group 1 and Group 2 at the time of the subjects' last appointment also had no significant difference, which was confirmed with the single-factor ANOVA test.

Several studies have shown that a lower age of implantation is highly correlated with an improvement auditory skill and development after continued consistent cochlear implant use; however this cannot be completely separated from the length of time the child lives with a severe-profound sensorineural hearing loss. Studies produced by Robbins et al. (2004), Sharma et al. (2003), Dorman and Spahr (2002) and others have consistently replicated that duration of deafness is a strong indicator to all auditory performance outcomes later in life, including in children. It is assumed that for young children, the shorter the duration of deafness the earlier they are receiving their cochlear implant(s). This in turn assumes that identification of the hearing loss is done early, and cochlear implantation is subsequently done soon after identification (Robbins et al., 2004). In particular, Robbins et al. showed that for children age 12-18 months, 19-23 months and 24-36 months all showed significant and speedy improvement in their mean IT-MAIS score. However the children in the 12-18 month group and the 19-23 month group both had significantly higher overall means in their final IT-MAIS score when compared to the group of children aged 24-36 months (Robbins et al., 2004).

While this study utilized the IT-MAIS questionnaire instead of obtaining objective speech awareness or speech reception thresholds as the present study did, this research exemplifies one of several studies that emphasize the need for early cochlear implantation in children diagnosed with severe-profound hearing loss in order to have the best chance of obtaining auditory skills later in life.

Geers, Brenner and Davidson (2003) conducted a study that utilized post-operative cochlear implant speech recognition scores, which included several tests of speech perception as well as a parent questionnaire. Geers and colleagues found that after 4-7 years of cochlear implant use children who received a cochlear implant under the age of 5 achieved the highest levels of speech understanding while utilizing both visual cues and speech recognition (Geers, Brenner & Davidson, 2003). These children obtained an average speech reception score of 80% correct while completing a variety of speech and language tasks. These speech reception scores obtained included easier language tasks as well as harder speech identification tasks (such as the ESP, WIPI, and MLNT) and were completed after the children had reached a minimum of 4 years use with their cochlear implant and who were at least 2 years old at the time of implantation. In addition to the speech measures utilized, parents of the children were also asked to complete an 11-item Auditory Response Questionnaire, which served to identify the child's auditory behaviors, the child's ability to care for and operate their cochlear implant, etc. While this study by Geers and colleagues is similar to the current study, no pre-operative ABR assessment was utilized to categorize the participants prior to assessing their speech perception outcomes post-cochlear implantation. Also, children under the age of 2 years were not utilized to complete the study and questionnaires were not utilized in the present study to obtain post-operative data. Interestingly, in contrast to several other studies mentioned in the afore mentioned literature review, Geers and colleagues failed to find a significant effect for age of implantation.

The study most similar to the present study design was completed by Nikolopoulous, Mason, Gibbin, O'Donoghue and Gerard (2000). Directly prior to cochlear implant surgery Nikolopoulous et al. observed promontory electrically evoked auditory brain stem responses (prom-EABRs) and placed children into two groups: one group had a clear wave V, and the other had no observable wave V (Nikolopoulous et al., 2000). Using a variety of open set and closed set speech tasks, as well as the CAP and Speech Intelligibility Rating (SIR) to assess speech outcomes of both groups, no correlation was found for either group regarding speech outcomes and the presence of absence of a pre-operative prom-EABR (Nikolopoulous et al., 2000). While the method of collecting the pre-operative ABR and speech reception testing was different, this study was the closest in methodology as found by this author and is commensurate with data collected for this research study.

While no other study known to this author directly correlates with the design and parameters of this data review, the majority of similar studies have shown that the younger a child with severe-profound sensorineural hearing loss is implanted with a cochlear implant the better their speech outcome scores will be. The three studies reviewed in the above do consider auditory skill development as measurable on parental questionnaires; however Nikolopoulous et al. is the only one of the two that attempts to predict speech reception outcomes in children post cochlear implantation based on pre-operative electrophysiological results. While the diagnostic speech reception batteries developed by Geers et al., as well as test batteries completed by other authors and studies, give a clearer pictures as to how children with cochlear implants progress in their speech reception abilities it does not easily quantify this, as multiple tests are required to obtain results. The need to quickly and efficiently obtain this data and subsequently be able to predict speech reception outcomes post cochlear implantation is still a need that audiologists should continue to address.

While cochlear implantation is a proven option for deaf children to develop spoken language there are still no predictive measures that will indicate a child's success with speech perception post-implantation. Several new avenues are being pursued utilizing PET scanning (see Chapter 1), yet the ABR has yet to be exhausted as a possible method for predicting speech outcomes. While this study fails to find an association between a pre-operative presence or absence of an ABR wave V and post-implantation speech outcomes, there is room for possible improvements in this experimental design and the following considerations should be taken into account for further studies. Not all confounding variables could be accounted for given the design of this experiment. Confounding variables that could not be accounted for include physiologic integrity of each subjects peripheral and cortical auditory pathway, motivation of the parents to pursue and implement habilitation services post implantation, speech processing strategy selected by the cochlear implant team best suited for the subject, utilization of device combinations (one cochlear implant, two cochlear implants, or one cochlear implant and hearing aid), the patients gender, and quantity and quality of auditory input. For future studies, it is recommended that a regimented follow up protocol be established, as well as a habilitative services protocol that includes speech and language instruction by a speech-language pathologist, in conjunction with other early intervention services as needed. Consistency in speech outcome measure should also be accounted for, as not all subjects in this study were able to complete a SRT measure, and a SAT measure had to be included in the data instead.

While physiological measures are being developed to better predict which children will succeed with cochlear implants, it is still necessary to exhaust all avenues of possible predicted success measures through speech testing, as not all industrialized or developing counties will have access to this expensive equipment. The ABR is an excellent example of a less-expensive piece of auditory diagnostic equipment, and every measure should be taken to ensure that its full potential in assessing hearing loss has been extinguished. The ability to predict speech reception outcomes post cochlear implantation for a particular child would very likely assist many parents in the often difficult decision to implant their child or not, and audiologists should continue to peruse this avenue until all resources have been exhausted.

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